ІНФОКОМУНІКАЦІЙНІ ТЕХНОЛОГІЇ ТА ЕЛЕКТРОННА ІНЖЕНЕРІЯ
INFORMATION AND COMMUNICATION TECHNOLOGIES,
ELECTRONIC ENGINEERING

№ 4 (2), 2024

https://doi.org/10.23939/ictee2024.02.093

EFFECTIVENESS ENHANCEMENT OF TRAFFIC CAMERAS BASED ON VEHICLES' AVERAGE SPEED CALCULATION

O. Urikova, K. Morhoiev [ORCID: 0009-0009-5347-6022], **D.Chornyi** [ORCID: 0009-0002-1035-071X],

Lviv Polytechnic National University, S. Bandery Str., 12, 79013, Lviv, Ukraine

Corresponding author: K. Morhoiev (e-mail: kostiantyn.y.morhoiev@lpnu.ua)

(Received 1 June 2024)

The analysis of calculating the vehicle speed between two automatic speed cameras within the framework of traffic violation detection demonstrates that using the average speed metric enhances speed limit compliance accuracy. This method reduces the possibility of evading responsibility for violations through temporary speed reduction before cameras. These systems employ usage of existing road cameras infrastructure to determine the minimal travel path of vehicle passing two cameras placed at a certain distance apart to measure the average speed of travel. Technical aspects of implementing the proposed system include utilizing cloud computing for data processing and storage, which reduces infrastructure costs. The system employs the possibility of usage of machine learning algorithms to predict travel time between cameras, considering various factors such as road conditions and speed limits. This approach ensures high calculation accuracy and reduces the number of false violation alerts. To further reduce the possibility of false violations, it is suggested to only use speed limitations based on the traffic signs on the road intervals of the calculated minimal path between two cameras that the vehicle has passed. Implementing the system requires the development of new software for data analysis and integration with existing traffic control systems. This includes designing algorithms to determine the minimum required travel time between cameras and calculating the average speed based on these data. Additionally, methods must be developed to detect and handle exceptions, such as road stops, or route changes, which can affect calculation accuracy. The feasibility of practical implementation of the system was investigated based on the existing infrastructure of traffic cameras in the city of Lviv. Possible minimal routes between cameras were analyzed and compared to the avarage passing speed of vehicles of different categories. The modulated results indicate that such a system would be an effective addition to the traffic control system, while requiring relatively low financial and engineering efforts.

Keywords: *average speed, automated processing, speed enforcement camera*

1. Introduction

Automated speed control technologies are widespread in many parts of the world. Research consistently confirms the significant safety benefits achieved through these technologies. However, there are substantial variations in the nature, extent of use, and acceptability of automated speed control technologies, especially when used as the primary method for enforcing speed limits.

Ukraine, in turn, demonstrates its readiness to introduce innovative solutions not only in the commercial sector but also to change laws to be a modern legal state.

One of the problems arising on Ukrainian roads is the low density of data cameras and the violation of rules beyond the camera's reachability. A significant portion of drivers exceed speed limits, and upon seeing the road sign 5.76 "Automatic video recording of traffic violations," they simply reduce their speed upon seeing the road sign[1]. Thus, the effectiveness of such cameras in measuring speed is quite limited and they have substantial "blind" spots.

With the improvement of roads and the growing numbers of people with driving licenses, the number of road accidents also increases. In 2023, there were 23,642 road accidents in Ukraine, in which 3,053 citizens died and another 29,502 people were injured [2].

Therefore, the issue of increasing the efficiency of the use of automated traffic monitoring cameras is of great concern to society. With the introduction of automated cameras, speed control has become more objective, reducing the risk of human error or unfair treatment.

2. Determination of the vector for building an automated traffic monitoring system

Technological advancements continue to progress rapidly, with artificial intelligence increasingly being integrated into various facets of our lives. One notable example is the use of AI for automatic license plate recognition in the context of recording traffic violations through traffic cameras.

The main researches related to traffic cameras are divided into specific areas. Some of them are focused on the accuracy of data calibration of license plate recognition, as researched in Sayed Navid's article [3]. Others are focused on the improvement of the quality of images, as it is challenging to obtain a disctinct image at high vehicle speeds and therefore difficult to recognize (for example, the research conducted by Lee Yangsang on the use of two cameras to enhance pictures quality [4]). There are also studies related to traffic flow prediction, anomaly detection, and vehicle tracking [5].

We have attempted to propose a method for identifying speed violators based on the minimally required travel time over a section of the road between two or more cameras.

Currently, there is a method for determining the average speed of travel between two points, which involves two linked cameras placed at a distance of 200 meters to several kilometers apart, or cameras mounted on a single pole, with one directed at the front license plate and the other at the rear license plate of the vehicle [5].

It is well-established that all traffic cameras are connected to a single network, thereby enabling on-demand access to captured photos for specific uses. Traffic cameras operate within a shared network infrastructure where images and data are managed through centralized servers. This network allows for real-time processing, storage, and retrieval of traffic footage, thereby enhancing the efficiency of traffic monitoring and enforcement. The interconnected system facilitates the handling of large volumes of data, ensuring that traffic images are systematically cataloged and accessible for analysis and decision-making [6]. The processing of these images is primarily carried out using artificial intelligence, with human intervention required only in exceptional cases [7].

Thus, the existing system of automated speed evaluation cameras can be expanded and supplemented with the requirement to take photos of every vehicle passing by. There is also a need to extend the capability of the image processor and data storage to cover the processing and storage of data about vehicles that have passed by the camera's place.

In addition to the need to expand the capabilities of the photo analyzer from the camera, it is also necessary to attract resources that will determine how much time is needed for the minimum necessary travel time between the two cameras. For this part of the application, it is purposed to use a cloud-based solution, as building an independent system of speed prediction possess several difficulties, such as managing information about road conditions and path availability for certain vehicle categories as well as accounting possible changes in road parts speed limitations that can be changed over time. For this, we will use Google's pathfinding tools – Google Maps Routes API [8].

We can calculate the minimum time required to travel between two points (in our case, cameras) by setting up the necessary parameters, based on the speed limit for the road sections, and disregarding real-time traffic conditions (the "predicted travel time" settings). Usage of minimal travel time based on the road signs instead of predicted avarage time is necessary for two reasons. The first reason is the complexity of organizing such a system – for each vehicle, it would be necessary to determine predicted travel speeds at the starting point for each possible future point, as real-time measurements do not provide data based on past information. The second reason is the difficulty of implementing a legal basis for determining the fine based on a system that is constantly changing.

In summary, the primary source of truth should be the graph of the shortest time built between a camera and its nearest neighboring cameras. As a result of the construction of such a graph, it is possible to obtain a large map of interregional connections with clusters of smaller, but more complex graph subsystems within regional centers and large cities.

A comparison of speed control approaches existing in Ukraine [9] with the proposed one is given in the table. 1.

Table 1

Comparison of speed control approaches

Name	**Modern systems (TrueCam, Vizyr)**	**Existing connected systems (Dozor) [9]**	**Proposed system**
Speed measurement	Instant	Allied, instant after passing the second camera	Fast processing, high connectivity, queried after second camera is passed by
The amount of blind spots	All the way except for the area in front of the camera	The entire route, except for the distance between the two cameras and the area in front of the first camera	The inability to accurately calculate the average speed if the vehicle had stops
Maintenance cost	Same as for existing one		A server is required for processing and medium-term data storage, along with technical support
Development cost	Existing system		A modular system with potential for development. Low costs for developing the basic functionality.
Economic prediction	282 million (statistics for 2021)		With a minimum increase in efficiency of 1%, the additional profit will be at least 2.8 million UAH.
Legal Component	Existing System		The need to adapt the law to proposed innovation

3. Determination of basic indicators and development of the algorithm for the vehicle speed identification system

Since speed limits are regulated by rules for road safety improvements, the primary indicator of the successful implementation of such a system is the reduction in mortality and injury rates among road users. From an efficiency standpoint, this system must meet certain criteria. The most important criterion for this system is measurement accuracy, as the measured information will be used to confirm that a certain vehicle has violated traffic rules and should not impose additional burdens on the judicial system due to mistakenly issued fines.

Data processing speed is also critical, as it affects the system's responsiveness and its ability to operate in real-time. This means that the system must quickly process the received data and calculate the travel time of vehicles in a suitable time.

The reliability of the system is determined by its stability over a long period and its ability to adapt to various operating conditions, including changes in the environment, traffic, and routes. The system must periodically update the graph of the minimum required travel time. This is necessary for situations when, for example, a section of the road that forms the fastest route is closed for repair, and now the fastest route is different. Or in reverse situations: a new bridge or road opens after repairs, providing a faster route. Such scenarios could lead to mistakenly issued fines. To avoid this, the minimum speed graph needs to be updated periodically, for instance, daily.

Additionally, it is worth mentioning the system's integration, which is important for its ability to coexist with existing systems and the potential for synergy with them, ensuring a comprehensive approach to traffic management.

To build a centralized system for processing the average speed of each vehicle individually, it is necessary to model the behavior of the Storage and Processing Center (SPC) when adding a new camera, as well as the main logic of the system when a vehicle passes by the first camera and then by another.

An important detail in this development is protection against “zombie objects” – vehicles that pass through one camera, but rarely reach the point of another one, leaving their footprint in the system, but never reaching required conditions to be fully processed. Over time, this can lead to the need for increased operational memory capacity due to memory leaks. Such situations can occur, for example, when the owner of a car lives in the area between two cameras, or if there are multiple possible routes (e.g., when passing through a city) due to the existence of more than one possible path.

Cameras are proposed to be added to the system manually, as this is a relatively rare event. Information about the camera should include at least the camera identifier, its geographic location, and neighboring cameras. Since a camera can be unidirectional, the number of neighboring cameras may differ depending on the direction of travel. After adding a camera, the Storage and Processing Center (SPC) must calculate the minimum travel time to neighboring cameras and also recalculate the minimum time for these cameras and update the list of neighbors for them.

The next step is to create the business logic for the main part of the system, specifically the logic for passing cameras and calculating the average speed according to the speed limit between cameras. At this stage, it is necessary to consider the logic of storing information about the vehicle in the system's memory and the need to update data if the vehicle passes the next camera while following the speed limit.

A realistic approach might involve storing information only about the first camera or storing data about all the cameras the vehicle has passed through. The first option helps to reduce the average speed calculation, which allows for lowering the deviation from the average speed over the entire route. However, this method might consider stops and parkings, leading to a derogation of the average speed.

Storing data about all passed points has the disadvantage of increasing memory usage without improving the system's efficiency. Therefore, the option of storing information only about the first camera and comparing travel time data when the second camera is passed has been chosen. The algorithm for this behavior is described in detail in Fig. 1.

In the algorithm, it can be seen that data is overwritten in the SPC regardless of whether the driver is violating the speed limit or not. This is explained by the fact that a vehicle can violate multiple traffic laws in succession, and thus, regardless of whether the driver has violated the speed limit, the information about this passage is overwritten when passing by another traffic camera.

Thus, a vehicle enters the system when it passes a traffic camera and it is removed from the system only when the specified time limits are exceeded.

As shown in the algorithm above, this logic requires a centralized data processing system, as well as information that will come from existing cameras through existing communication channels. Therefore, the costs for equipment are quite low, but this project not only can be economically beneficial but also impacts the safety of road users' lives.

Apart from the algorithm provided, before moving on to mathematical modeling and calculating the system's effectiveness, it is necessary to define the conditions under which speed is considered to be above the permissible limit. Quoting the publication on the site thepage.ua [10]: “A speed limit violator is considered to be a driver who exceeds the permitted speed. The allowable speed excess is 23 km/h. For example, in cities, this will be 73 km/h (50 allowed + 20 — allowable excess + 3 — additional measurement error).”

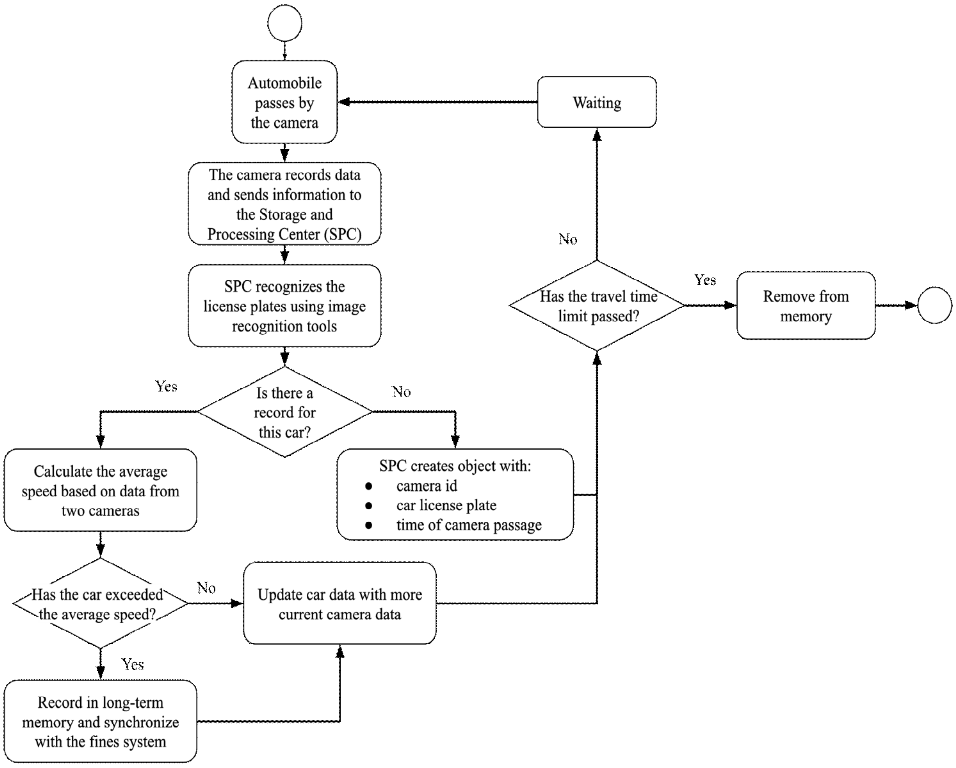

Fig. 1. Algorithm of the SPC operations with traffic camera data

The calculation of the average allowable speed of movement must be carried out according to the formula (1).

$$V_{av} = \frac{\sum_{n=1}^{k} \left(V_n + V_{n.add} + \delta\right)}{k}, \quad (1)$$

where V_n – the allowable speed on a given section of the route, k – the number of sections with different speeds, $V_{n.add}$ – the allowable speed excess on a certain section of the route, δ – probable device error

However, since according to the traffic rules in Ukraine, the allowable speed excess does not depend on the base allowable speed and is a constant number, the formula above can be simplified. Additionally, since the error δ is an error that accounts for the camera's readings at a certain point in time, it can be neglected when calculating the average speed excess (2):

$$V_{av} = \frac{\sum_{n=1}^{k} \left(V_n\right)}{k} + V_{n.add} = \frac{\sum_{n=1}^{k} \left(V_n\right)}{k} + 20. \quad (2)$$

By using data from Google, we can obtain the time t and the distance l between two cameras. Accordingly, the total speed on the sections can be replaced with the average speed over a continuous section of the route (3):

$$V_{av} = \frac{l_g}{t_g} + 20, \quad (3)$$

where the index g indicates the use of data from the system for determining the required time, which in turn is obtained from Google.

4. Mathematical justification of the efficiency of the average speed calculation system

Initially, it is necessary to model an abstract graph. This modeling allows us to represent the road network as a graph, where nodes correspond to the locations of the cameras and edges represent the road segments connecting them. By analyzing this graph, we will be able to simulate various traffic scenarios and evaluate the effectiveness of average speed calculation methods.

For this, we use a real map with the placement of automated traffic enforcement cameras in the Lviv region (Fig. 2).

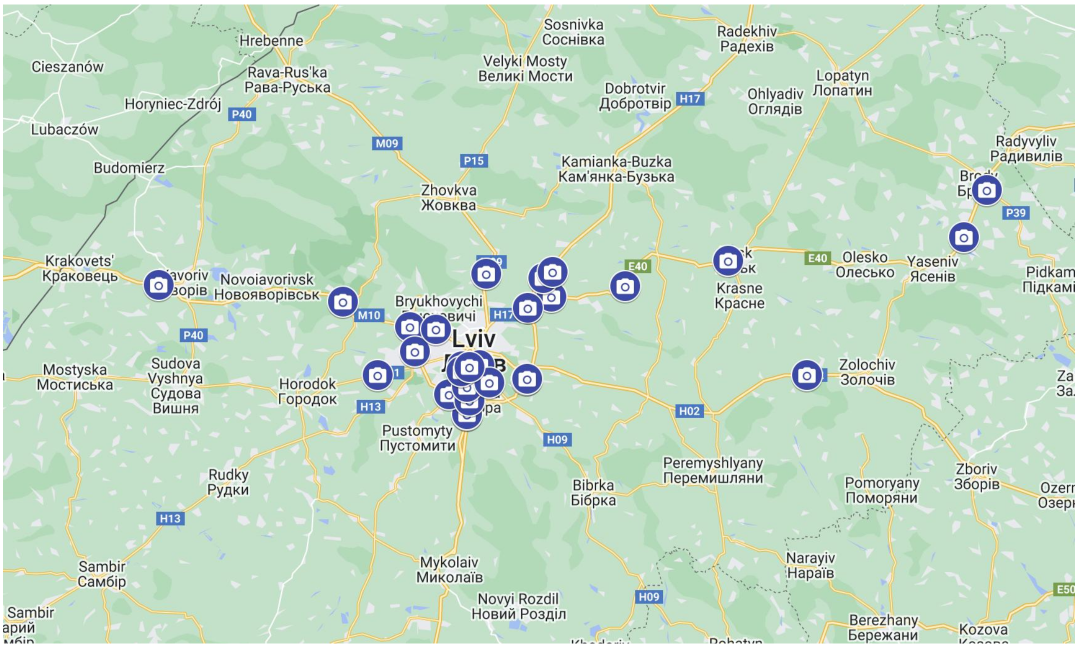

Fig. 2. Placement of automated speed enforcement cameras

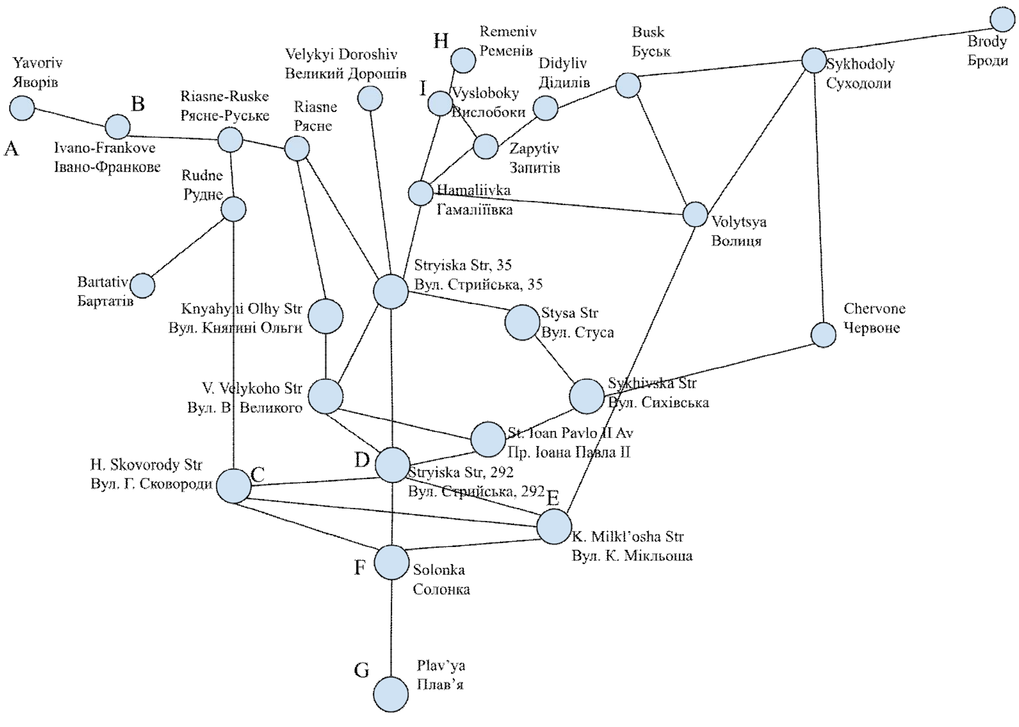

Fig. 3. Graph of the connections between cameras

The data was taken from the official website of the Ministry of Internal Affairs of Ukraine [11] and does not include cameras near the Plav'ya village on the border with the Zakarpattia region, in order to provide greater detail of the cameras in the screenshot above. By analyzing the main roads and the probable routes between cameras, a schematic graph was obtained, as shown in Fig. 3.

The probability of passing by a camera is influenced by the number of road branches, their weight, the length of the road, and the presence of settlements along the route between cameras. However, this does not affect the speed of travel but only the efficiency of the use of SPC resources.

To check the efficiency of the speed enforcement cameras, the following connections between cameras were selected (Table 2).

Table 2

Cameras' data

Camera Location 1 (Letter on the Graph)	Camera Location 2 (Letter on the Graph)	Distance (km)	Required time (h)
Yavoriv (A)	Ivano-Frankove (B)	32	0.52
Lviv, Stryiska St., 292 (D)	Western Bypass of Lviv (C)	8.4	0.16
Lviv, Stryiska St., 292 (D)	M06 Kyiv-Chop 552 + 486 (E)	3.7	0.06
Lviv, Stryiska St., 292 (D)	M06 Kyiv-Chop 555 + 662 (F)	8.8	0.1
M06 Kyiv-Chop 555 + 662 (F)	M06 Kyiv-Chop 685 + 309 (G)	129	1.87
N17 Lviv-Radekhiv-Lutsk 4 + 898 (H)	N17 Lviv-Radekhiv-Lutsk 3 + 064 (I)	1.8	0.03

Depending on the input data, the used travel time for the given section was calculated at speeds ranging from 50 to 200 km/h. Depending on the distance, the calculated minimum travel time, and the average speed of the vehicle, the curves differ in their intersection with the allowable speed, where the red line indicates the minimum required travel time and the blue line represents the time taken according to the average speed at which the driver is traveling. The calculation results are shown in Fig. 4.

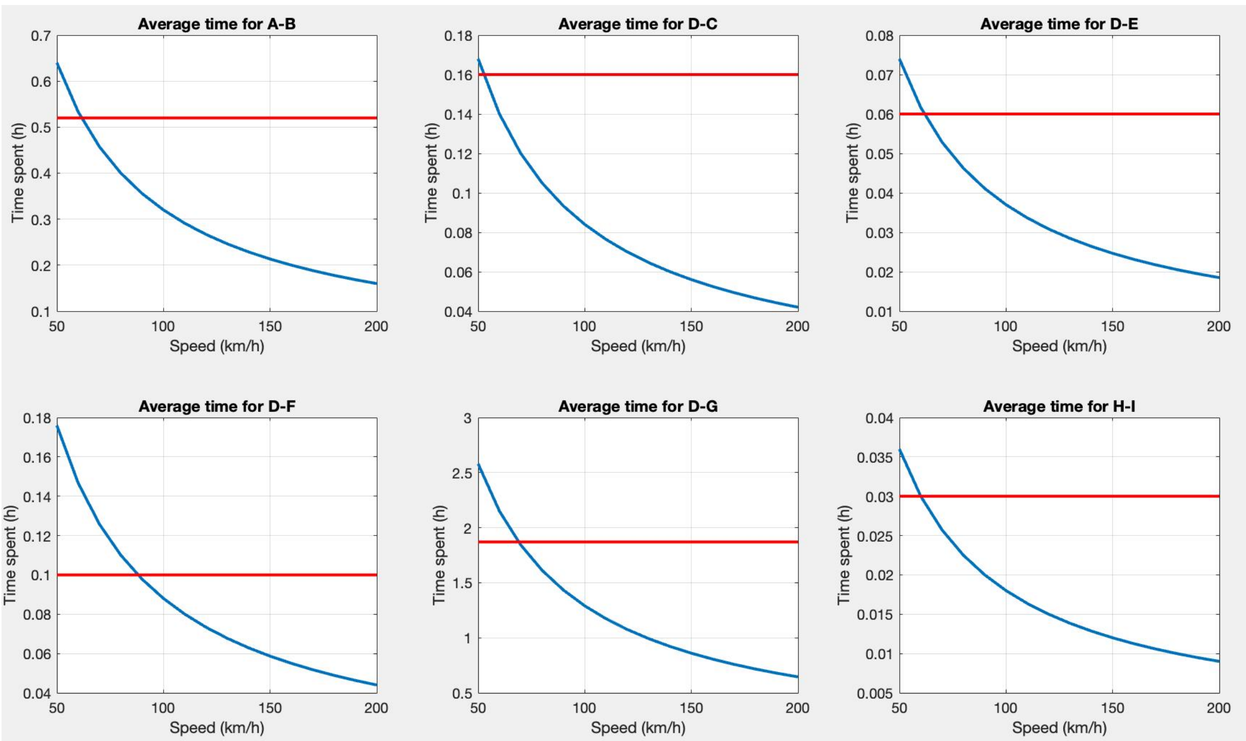

Fig. 4. Graph of time spent relative to the vehicle's average speed

All vehicles whose travel data lies above the red line are not violators. However, those who traveled at an average speed greater than the allowed speed have data points that fall below the red line. Accordingly, the time spent for such objects will be lower, and they will be considered as having driven in violation of specified rules.

The calculations above are based on the vehicle's average speed. Lets consider scenarios where a vehicle is stationary for a certain percentage of the time: this could be due to a traffic jam, a stop at a gas station, or a lunch break. Let's model the delay with idle times of 1%, 10%, 25%, and 50% of the total time spent.

Fig. 5 shows the families of characteristics with added delays corresponding to these percentages of the time spent. Green represents the minimum required time to travel the given section, blue represents a 1% delay, red represents a 10% delay, yellow represents a 25% delay, and purple represents a 50% delay.

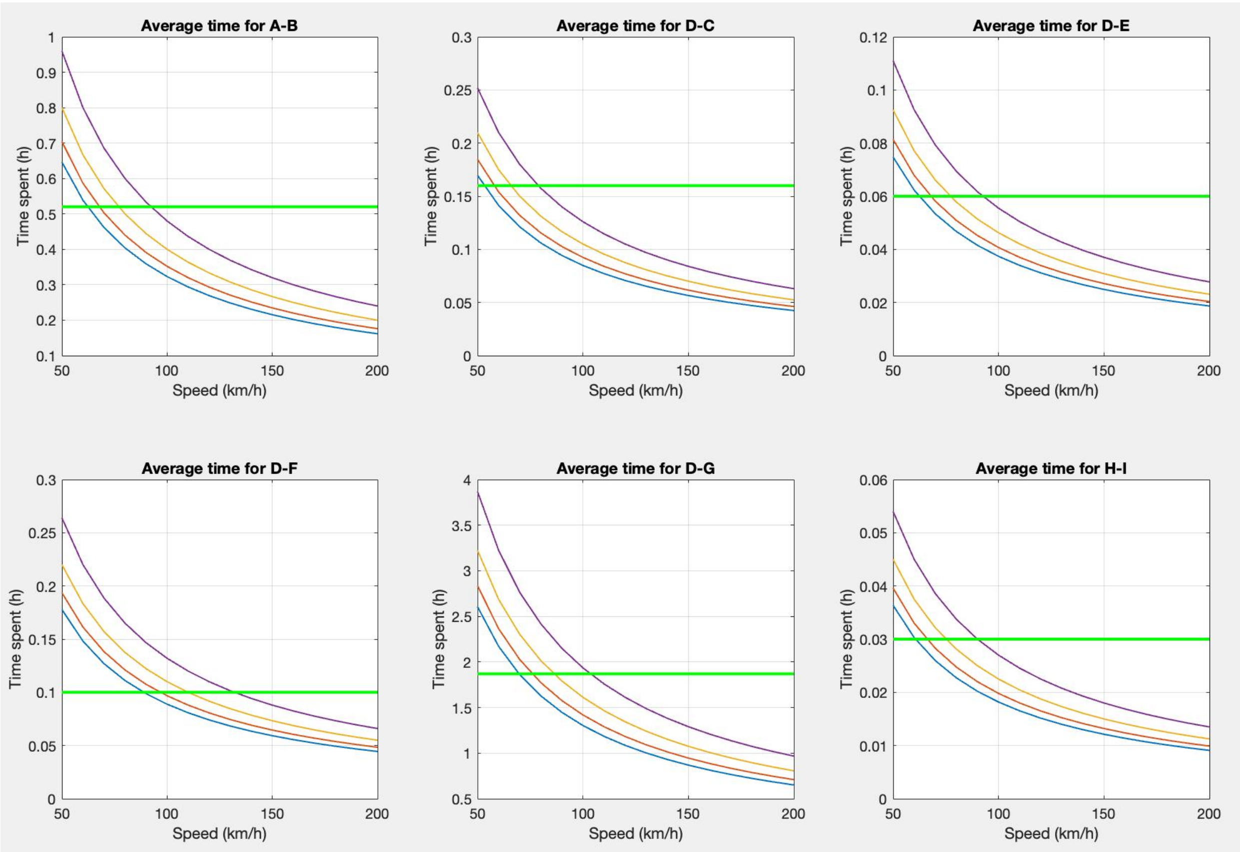

Fig. 5 Graph of time spent relative to the vehicle's average speed with considered delay

The figure illustrates that increasing the frequency of pauses during driving can potentially lead to an increase in the average speed required to cover the same distance. The data from the graphs suggest that the proposed algorithm is most effective on medium-distance highway sections. These sections typically experience fewer traffic jams and a lower likelihood of stops compared to long-distance highways. Therefore, implementing such a system can significantly enhance road safety and reduce the number of traffic violations. Moreover, the system's ability to identify speed violations and ensure compliance with traffic regulations can contribute to a reduction in accident rates and improve overall traffic management.

Conclusions

We considered the possibility of implementing a system for detecting events of exceeding traffic speed limits. The proposed mechanism for the system's operation that is based on a time comparison of distance travel with expected data for various transport systems. In this mechanism, we considered the possible system limitations based on the factors that might reduce the chances of identifying the vehicles violating the speed limits, such as road stops and low camera density across the roads.

The feasibility of practical implementation of the system was investigated based on the existing infrastructure of traffic cameras in the city of Lviv. The modulated results indicate that such system would be effective addition to the traffic control system, while requiring relatively low financial and engineering efforts.

References

[1] Qin, Y. and Chen, Y. (2020), "Quantifying the Effects of Visual Road Information on Drivers' Speed Choices to Promote Self-Explaining Roads", Int J Environ Res Public Health. vol. 17, issue. 7. doi: 10.3390/ijerph17072437

[2] Patrol police (2023), Official statistics of road crashes: DTP-12-2023, available at: https://patrolpolice.gov.ua/statystyka/ (accessed April 30, 2024)

[3] Raza S. (2019), "Artificial Intelligence based Camera Calibration", 15th International Wireless Communications and Mobile Computing Conference (IWCMC). doi: 10.1109/IWCMC.2019.8766666

[4] Li Ya. and Zenh. H. (2023), "The Key Research of High Speed Camera Based on Multiple Core CMOS Sensors", Signal and Information Processing, Networking and Computers, pp. 245-252. doi: 10.1007/978-981-19-9968-0_29

[5] Shuai Hua, Kapoor M. and Anastasiu D. (2018), "Vehicle Tracking and Speed Estimation from Traffic Videos", IEEE/CVF Conference on Computer Vision and Pattern Recognition Workshops (CVPRW). doi: 10.1109/CVPRW.2018.00028

[6] Brindley Group (2024), "Everything about speed cameras", available at: https://www.brindley.co.uk/news/everything-you-need-to-know-about-speed-cameras (accessed April 28, 2024)

[7] Mandal V., Mussah A.R. and Jin P. (2020), "Artificial Intelligence-Enabled Traffic Monitoring System", Department of Civil and Environmental Engineering University of Missouri-Columbia, preprint. doi: 10.20944/preprints202009.0725.v1

[8] Official Google Maps documentation (2024), "Routes API", available at: https://developers.google.com/maps/documentation/routes (accessed April 25, 2024)

[9] Ferocon group (2024), "The Dozor system for monitoring and violation detection", available at: https://ipcom.ua/uk/dozor (accessed April 30, 2024)

[10] The Page publisher (2021), "What do you need to know about allowed speed limits", available at: https://thepage.ua/ua/news/shvidkisnij-rezhim-ukrayina-2021-sho-potribno-znati-pro-dozvolenu-shvidkisti (accessed April 29, 2024)

[11] Ministry of Internal Affairs of Ukraine (2024), "Cameras' addresses and speed limits", available at: https://mvs.gov.ua/ministry/projekti-mvs/avtofotovideofiksaciya-porusen-pdr/adresi-kamer-fotovideofiksaciyi-ta-dozvolena-svidkist-ruxu-1 (accessed April 28, 2024)

ПІДВИЩЕННЯ ЕФЕКТИВНОСТІ ВИКОРИСТАННЯ КАМЕР ДОРОЖНЬОГО РУХУ НА ОСНОВІ РОЗРАХУНКУ СЕРЕДНЬОЇ ШВИДКОСТІ

Оксана Урікова, Костянтин Моргоєв, Денис Чорний

Національний університет «Львівська політехніка», вул. С. Бандери, 12, 79013, Львів, Україна

Аналіз розрахунку швидкості руху транспортного засобу між камерами автофіксації показує, що використання показника середньої швидкості підвищує точність оцінки дотримання швидкісного режиму. Запропонована система використовує існуючу інфраструктуру дорожніх камер для визначення мінімального шляху руху транспортного засобу, що фіксується двома або більше камерами, розташованими на ділянці шляху транспортного засобу. Технічні аспекти впровадження запропонованої системи включають використання хмарних обчислень для обробки та зберігання даних, що зменшує витрати на інфраструктуру. Оцінка розрахунку граничного часу враховує можливість використання алгоритмів машинного навчання для прогнозування часу руху між камерами, враховуючи різні фактори, такі як дорожні умови та обмеження швидкості. Для подальшого зменшення можливості хибних результатів оцінкки пропонується використовувати обмеження швидкості, засновані на дорожніх знаках на інтервалах дороги мінімального розрахованого шляху між двома камерами, які пройшов транспортний засіб. Впровадження системи вимагає розробки нового програмного забезпечення для аналізу даних та інтеграції з існуючими системами контролю дорожнього руху. Це включає розробку алгоритмів для визначення мінімально необхідного часу руху між камерами та розрахунку середньої швидкості на основі цих даних. Крім того, необхідно розробити методи для виявлення та обробки виключень, таких як зупинки на дорозі або зміни маршруту, які можуть вплинути на точність розрахунків, а також можливі зміни швидкісних обмежнь та найменших шляхів між камерами. Можливість практичного впровадження системи була досліджена на основі існуючої інфраструктури дорожніх камер у місті Львові. Були проаналізовані можливі мінімальні маршрути між камерами та порівняно час їх проходження із середньою швидкістю проїзду транспортних засобів різних категорій. Модульовані результати вказують на те, що така система буде ефективним доповненням до системи контролю дорожнього руху, вимагаючи при цьому відносно низьких фінансових та інженерних зусиль.

Ключові слова: *середня швидкість, автоматична обробка, камера автофіксації швидкості*

.